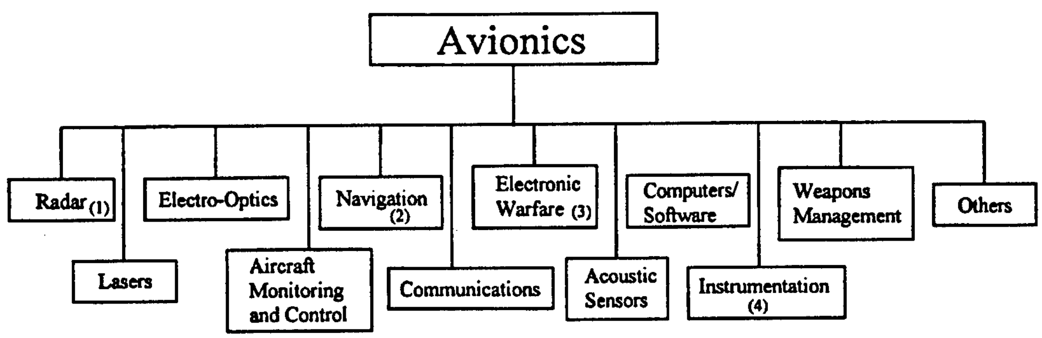
1.0 INTRODUCTION

The purpose of this document is to provide a basic introduction to the topic of developmental[1] avionics flight test. The target reader is the novice, just being introduced to the subject, such as a student at one of the test pilot schools, or a person just beginning in the field. The paradigm used in constructing the book was the curriculum at the test pilot schools, particularly, the United States Naval Test Pilot School, which has an avionics flight test specialization. There are many similarities between the flight test techniques that follow and those taught at the schools.

Figure 1 provides one definition of the categories of systems included in the field of avionics. Unfortunately, space constraints do not allow discussion of all of these categories in one AGARD publication and thus three are singled out: radar, electro-optical and navigation. As at the test pilot schools, the teaching technique chosen here is demonstration. The intent is that if the student can be made to understand the development of the sample test techniques shown in this book, he or she can then extrapolate to different systems and platforms. A thorough understanding of the test development process has an added benefit. It is plausible that the tester may some day



(1) Ref 50 is a description of air-to-air radar test techniques.
(2) At the time of this writing, an AGARDograph was chartered providing a detailed description of radio navigation testing. Ref 52 is an excellent treatment of stand-alone Global Positioning System (GPS), hybrid GPS and fully coupled Inertial/GPS testing.
(3) At the time of this writing, an AGARDograph was being chartered covering the subject of Electronic Warfare testing.
(4) The volumes of AGARDograph 16 and 300 relating to instrumentation are included as references.

Figure 1: Categories of Avionics

[1] Developmental testing is performed as part of the iterative design process. Data derived from developmental testing is primarily intended to measure whether the system has met its intended functional requirements, and if not, to provide data useful to the designer for improving the design. Note that this type of testing is distinctly different from operational testing. Operational testing is performed by the intended users (vice professional testers and engineers) in the intended operational environment as a final "dress rehearsal" for the system. It is important for the developmental tester to remember that when he or she has determined that the system has completed the developmental phase of testing that it must then pass operational testing. This operational requirement will necessarily influence the type of testing performed in the developmental phases of the iterative design process.

be presented with a completely new class of system, for which there are no previous techniques developed. If the logic of the development of the existing techniques described here is understood, then the tester will be able to invent the new ones as required.

The three classes of systems were chosen for several reasons. First, these are the same systems emphasized at the schools, providing a history of successful test pilot training. Next, it is possible to develop a totally unclassified discussion within the three chosen areas that is releasable in open literature. Electronic Warfare was not considered due to security issues. Computers and software were not discussed because even a basic primer on this subject would require a chapter larger than this document. Aircraft monitoring and control systems testing cannot be fully discussed without considering their effects in terms of airframe handling qualities and performance. These topics were beyond the scope of this document. In the final analysis, length precluded a discussion of even some of the remaining nine subjects and the three emphasized at the schools were selected for treatment. A fourth, Stores Management Set Testing, was added at the suggestion that the addition of a single electro-mechanical-electronic system would add depth to the document.

Since this book will only provide an introduction to the avionics test subject, it is envisioned that eventually, more advanced volumes will be written for each of the avionics categories. AGARD documents are included as references or are in work which provide partial documentation of radar, navigation and Electronic Warfare (EW) testing as well as an exhaustive series on airborne instrumentation. It is highly recommended that AGARD, or alternative organizations, champion the crafting of documents necessary to treat the balance of radar, navigation and electronic warfare testing, as well as the other areas not started. These documents would then serve as references for the active practitioner of avionics flight test.

This book emphasizes the most rudimentary form of the tests under discussion. This was done primarily to highlight the basic concepts on which the tests were designed. Typically, this implies that little or no instrumentation, test ranges or outside test assets are used in the tests which are developed. In many practical applications, more accuracy, documentation and numerical rigor are required. The reader must then refer to the more advanced flight test documents or in their absence, to experienced testers. It is noteworthy that in most cases, the basic concepts of the test do not change when more test assets are used and thus the utility of using the most rudimentary form of the tests for this introductory book.[2]

In addition to the teaching benefits, the very simple, rudimentary methods often have practical utility and should be documented. Often, these techniques are sufficient for the task at hand, when less accuracy and documentation are adequate. Money and time can thus be saved. Next, complete instrumentation also implies very complex, time consuming and expensive data reduction. There is often real pressure to constrict the time limits that test assets are available for a particular test. The rudimentary data collection can be taken concurrent with the more rigorous and the less accurate information used to adjust the next test event while data reduction occurs concurrently. The less accurate numbers can also be used to highlight problem areas and areas where requirements are easily met. This allows data reduction assets to be used where they are most needed.

Another important topic which was not documented in this book is the statistical implications of the tests, including the methods of sample size prediction, data convergence, etc. A few comments are made to highlight tests which have particularly troublesome statistical issues; however, the reader is cautioned to review any number of texts on statistics and experimental design prior to performing any rigorous testing. References 43 and 72 provide an introduction to the subject.

In order to facilitate the unclassified demonstration of the development and application of the sample test procedures, fictitious systems were chosen and placed within equally

[2]This presumption is highlighted on close comparison of the radar testing techniques outlined in this document and those presented by Scott [Ref. 50].

fictitious platforms. The specific procedures and data cards, which may include altitudes, airspeeds, target separations etc., are applicable to the sample system only and appropriate parameters must be chosen for the actual system/airframe combination under test.

In applying this document, basic knowledge in certain areas is assumed. The test planner should have a basic knowledge of avionics, although an electronics background is definitely not required. A familiarity with the operation of tactical aircraft is also important. A theory section is provided at the beginning of each of the three major sections with specific, amplifying information included in the general section of each test. The purpose of this information is to provide the reader with the knowledge necessary to comprehend the specific example system and test procedures that follow rather than a complete treatise of the entire subject. The intent is to preclude extensive outside reading to understand the test development process. When the time comes to apply the test development knowledge presented here to a real evaluation, an extensive understanding of the workings of the system under test is absolutely essential and the cursory treatment here will undoubtedly be insufficient, even if the systems are similar to the sample systems.

The layout of the individual test sections was carefully chosen with several goals in mind. Each test is fairly self-contained, exclusive of the information in the general theory sections. This allows the user of the manual to extract specific sections, reference them easily and quickly and review individual tests on the occasions where they are applicable to the system under test. In addition, the titles and contents of each section have parallels to the accepted test plan and technical report structure. Finally, the layout is similar to that used in the long accepted flying qualities and performance flight test manuals (see reference 47 for an example).

The test development process is manifested in the structure of the sections to follow. As mentioned above, the procedure is begun by exploring and fully understanding the design of the system under test. This understanding provides the insight necessary to stress the system and test it to its limits and also allows the calculation of the theoretical limits of the system. General theory applicable to each section is included in the first part of each section. Knowing the theoretical limits allows a more efficient test to be developed. This process is demonstrated later in the case study of section 7.

The choice of which parameters to test is best (and only) determined by a thorough knowledge of the workings of the system and its intended functionality. The process can be divided into two steps. First, the evaluator must define the required functionality of the system. The functional description should be defined in operational, vice engineering, terminology. This step requires a knowledge of the intended mission of the system. Secondly, the evaluator must choose the kernel of parameters which measure the performance of the required functionality defined in the first step. This task requires a thorough system knowledge. These parameters are then used as a guide for the development of the individual test procedures. The test procedures are designed to measure at least one of the critical performance parameters. The individual test procedures listed in the next three sections are titled according to the parameter under test.

The first subsection of each test procedure describes the purpose of the test, which more precisely defines the parameters under test. In the general section, the basic theory outlined in the beginning of the section is expounded upon as necessary to fully implement and understand the test procedure. The instrumentation requirements necessary to measure the parameters described in the purpose statement are then listed followed by the data required to document the parameter. Next, the procedure for performing the test is described in detail followed by a discussion of the post-test analysis of the measured data required to answer the purpose statement and the recommended format for presenting the test results. The last part of each test procedure is sample data cards used to perform the test procedure and for recording the data during actual testing.

In summary, the test design process can be described as outlined below. It may be necessary to change the order in which the tasks are performed as well as the relative importance of the tasks from test to test, but the list below will provide a guide for the general case.

(1) Research and understand the design specifications and operational use of the system under test. Use this knowledge to define the parameters critical to assessing the performance of the system and also as a means for calculating the theoretical boundaries of the system's performance.
(2) Precisely define the purpose of the test procedure to include the parameters to be measured during the test.
(3) Define the data necessary to calculate the parameter under test and assess the instrumentation requirements necessary to measure the data.
(4) Outline the detailed procedure necessary to perform the data collection effort.
(5) Define the analysis necessary to take the measured data and calculate or assess the parameter under test and then decide upon the proper presentation format to document the parameter.
(6) As a last effort, generate data cards that provide an outline of all information necessary to perform the data collection effort and record the results.[3]

2.0 AIR-TO-AIR AND AIR-TO-GROUND RADAR SYSTEMS TESTING

2.1 Introduction to Radar Theory

2.1.1 General

Radar (Radio Detection And Ranging) was first used operationally in 1937. This rudimentary system included a simple pulsed scheme to determine target bearing and range. [Ref. 9:p.1]. The first successful airborne radar was the Al Mark IV carried on the Bristol Beaufighter 19 in 1940 which used simple pulsed techniques to determine airborne target range [Ref. 56:p.2]. From these humble beginnings, radar has developed to the point that it has become the centerpiece in virtually every modern airborne weapon system. In the very simplest terms, a radar sends into space a Radio Frequency (RF) pulse of known characteristics, waits for the waves reflected off the target to return and analyzes the characteristics of the returned wave to derive information about the reflecting target [Ref. 39:p. 2.1].

2.1.2 Pulsed Radars

The simplest of radars are the pulsed radars. The operating principles of pulsed radars are based on the fact that RF energy propagates through space at a constant velocity. This velocity, strictly speaking, is applicable only in a perfect vacuum and is altered slightly by the atmosphere. Propagation velocity is a function of transmission frequency, and atmospheric molecular composition, temperature and pressure. The speed of propagation increases slightly at higher altitudes [Ref. 11:p. 81]. This effect is small; however, at the ranges and frequencies discussed in this section. For airborne test purposes, a "radar mile" of 12.36 microseconds can be defined, which is the time required for RF energy to travel out one nautical mile (nm) and then return [Ref. 27:p. 1-4.2].

The basic components of a pulsed radar include a transmitter, receiver, two antennas and a display [Ref. 60:p. 4]. Two antennas are included because the system requires a transmit antenna and receive antenna. In practice, a single antenna is time shared for both purposes. A duplexer is used to switch between the transmit and receive sides of the radar. The transmit side is connected only when actually firing a pulse and the receive side is connected to listen for returned pulses. [Ref. 56:p. 4]. This scheme prevents the transmit pulse from being directed to the receive side of the radar.

Transmitter antennas are usually designed to concentrate the transmitted pulse in as narrow a beam as possible. Similarly, receiver antennas are designed to receive signals within the same narrow beam. This phenomenon of essentially equal performance of the antenna in both transmit and receive modes is known as reciprocity and can be useful in designing tests [Ref. 36:p. 2.132].

[3]Refer to chapter 6 for a discussion of how to combine all the various tests, and their data cards, into an intelligent flight plan.